Recycler Ion Clearing Field Power Supplies

Introduction

The Ion Clearing Field (ICF) is a system that connects high voltage (HV) to the Recycler Ring (RR) Beam Position Monitors (BPM) electrodes for the purpose of collecting charged ions drifting in the beam pipe. One ICF power supply chassis is installed in each of six Main Injector service buildings, and provides HV to all the BPMS in the respective sector. A circuit in the RR BPM pre-amps isolates the HV from the BPM position measurement circuits.

The HV is distributed by (Red RG-58) with the up stream BPMs daisy chained using separate A and B electrode cables. The down stream BPMs are daisy chained in a like manner. There are approximately 35 BPMs in each of the US and DS strings. A map of all RR BPMs is shown in Fig. 5. The resulting four HV cables are routed upstairs to a relay rack and the PS chassis near the RR BPM electronic modules.

PS Chassis

Each PS chassis contains two small programmable power supplies, a four channel current measuring circuit board, an analog voltage and current monitoring circuit board and a logic board for status, local and remote control. The output of each of the small internal HV supplies drives two independent current measuring circuits. This arrangement provides four HV and four associated current reference outputs. The four HV outputs are then connected to the four HV cables leading to the BPMs. The cables can be arraigned to provide the common or opposite polarity voltage to the BPM A and B plates (1000 V Max). The cables are initially connected for opposite polarity to provide a voltage gradient across the BPM. See Fig. 1 for a simplified block diagram.

The chassis provides semi-independent control for the individual supplies. The voltage level is programmable, with both internal supplies tracking one reference input. The HV output can range from 0 to 500, with a scale factor of 50V/V. The polarities are programmable, using a common control bit for both supplies. The supplies can be set for either opposite or the same polarity. They are initially set for opposite polarities. A standard Camac CC218 is used for the power supply controller. See Fig. 2 and 3 for the Camac card I/O and Crate information. The power supplies are operated from Acnet parameter page R34, BPM sub pages 24 and 25 (Fig. 4)

The chassis can be switched to local control, from the front panel. All functions are available as noted above, except that 10 turn pots independently control the voltage of the internal supplies. PS voltages and current in each of the four channels can be monitored on the front panel LCD meter.

Included on the logic board are provisions for an over current trip, and safety system interlock s. The PS's have short circuit protection built in. The Safety Department has determined that this application is similar to the HV routing for Ion Pumps, and that it is not necessary to interlock the ICF power supplies. Status bits for indicating chassis local/remote, and individual supply on/off, and polarity. Refer to drawing 8130-ED- 356126 for a block diagram of the complete chassis.

High Voltage Power Supplies

The power supplies are the "RP" series manufactured by the "Emco High Voltage Company" The make nine models of this series with voltages ranging from 500 to 10KV all having the same physical size features and general specifications. The ICF uses the 0-500v "RP05" model. These supplies use TTL control for polarity and enable/disable (on/off), and a 0 - 10 Volt reference (always positive). They provide a voltage reference and polarity status bit outputs. Maximum current output of this model is 6 ma, with short circuit protection. A complete PS specification sheet is available in the document list below.

Current Measuring Circuit

The current measuring circuit is based on the Analog Devices (AD) AD204 isolation amplifier. Gain and low pass filter blocks have been added to a basic AD application circuit. This circuit measures the voltage drop across a large value resistor in series with the load. This resistor, buffer amplifiers, and part of the isolation amplifier, have a common ground, which floats on top of the HV PS output. The MADC analog to digital converter, which in this application is 12 bits bipolar or 2048(LSB value) determines the measurement resolution and range measured. The resolution (LSB value) and full-scale values in "engineering units" are chosen by setting the amplifier gain stages to the appropriate values. The current measuring schematic is shown on drawing 8130-EC-356129, which includes instructions for setting the amplifier gains. Referring to the schematic, the front-end gain is selected at Amp U1, and must be set for a maximum of 5 Volts at the AD 204's output. On the low voltage side of the AD 204 full-scale output range is set to 10v at Amplifier U3b. Using a 1 Mohm series resistor and gain at 10, the resolution becomes .488 nAmps, with full scale at $1.0~\mu$ Amps. The scale factor is 100~nAmps / V. Installing a 5 Mohm series resistor and with over circuit gain set at 200, the resolution becomes 4.88 pAmps with full scale at 10~nAmps. The scale factor would then be 1.0~nAmps/Volt.

Active low pass filters (one pole) are included on Amps U1, U3b, U5b, with an additional passive filter at the input of U5b. The filters all have a cutoff at approximately 1 Hz, with combined roll-off of -40 dB at 10 Hz.

Performance and Noise

This circuit has the capability of measuring low level current, at the pico amp range. However, the actual current resolution and accuracy is limited by the quality of the load, induced cable noise, the circuit gains, and filter Bandwidth. The initial gain setting gives a resolution of .5 nAmps, a range of 1 μ Amp with a scale factor 100 nA/Volt. Bench testing at this gain setting has shown the circuit to contribute errors of approximately .2 nAmps.

Fig. 6 is recent fast time plot showing leakage current present in one string of 35 BPMs and connecting cable. It also shows noise at the 2-nano-amp range, which is due to pickup on the on connecting cable. Temperature drift over several days, and thermal cycling, contribute errors of approximately .3 nAmps.

Fig. 7 is a fast time plot showing current during a Main Injector cycle. This interference produces up to 25 nAmps p-p currents during the MI ramp. Measurements by the instrumentation group have shown differences between the beam line ground and service building grounds to be as much as 50 mVolts during a MI ramp. Calculations show that this voltage will produce an unbalance and current error about equal to that shown on the plots.

Fig. 8 is fast time plot showing charging current for a string of BPMs and cable. The charging initially peaks to few μ Amps and then settles down to a few nAmps, which represents the BPM string leakage current. This current leakage is dependent almost entirely to the quality of the RG-58 high voltage cable. Current leakage ranges from about 10 nAmps for the better cables to several hundred nAmps for poor cables. Several cable sections have been identified and replaced because of high leakage or shorts. The charging time constant (TC) appears to be long for the final settling current. The plot shows (1) TC to be about 3 seconds, but final settling time runs out to about (5) TC. Calculations show that one string of 35 BPMs and cable should have a TC of about .5 sec, this combined with the amplifier filters 1Hz BW should give a TC of about 1 sec. Benches testing with actual cable (2000 ft) and simulated load agrees with the calculated value. The discrepancy is presently attributed to cable, connector and capacitor dissipation (or leakage).

Summary

The Ion Clearing Field Power Supplies work well, and discounting the connecting loads, are capable of measuring the current draw well into the pAmp range. They are presently set up with gain and BW values for measuring in the nAmp range, which they are capable of doing on the better cables, despite the cable leakage and induced MI ramp noise. Measurements should done after the ramp period and take into account the offsets caused by cable leakage. Zero offset compensation and sampling circuits could be added if warranted.

The Power Supplies (alone) are capable of measuring currents in the pAmp range, with the scale factor and BW change, noted previously. A more critical adjustment of gains and circuit offsets would also be required. However the present cable is questionable. This installation uses a single ended connection and will always pick up the MI ramp due to the different ground potentials. The cable does not have uniform characteristics. Each string has different leakage current. A spare PS is available and will be available for suggestions to improve the system.

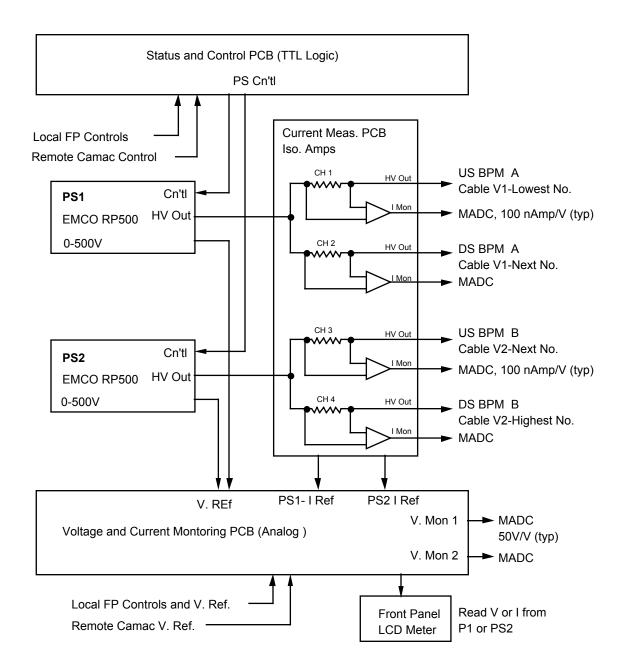


Fig. 1 Block Diagram of the Ion Clearing Field Power Supply

Drawings on file:

ICF Chassis Diagram / Schematic	8130-ED-356129
ICF Current Measurement Board Sch.	8130-EC-356126
(Previous P-Bar version)	8000-EC-266290
ICF Control Board	8130-EC-356127
ICF Analog Board	8130-EC-356128

Drawings and other items available Beams WNT/2000 server:

On WNT/2000 Beams Div. Server, log on to: "rfinst.bd on beamssv1" At the "Y" drive go to: >public>Instrumentation>J. Fitzgerald>Ion C. F. Folder

PDF Files

ICF PS Block Diagram	8130-ED-356129.pdf
ICF PS Control Board	8130-EC-356127.pdf
ICF PS Analog Board	8130-EC-356128.pdf
List of Recycler BPMs	Recycler BPM Loc.pdf
Camac Crate info. and CC218 I/O	ICF PS CC218 I/O.pdf
HV Power Supply Data Sheet	HV PS data sheet.pdf
ICF PS Parts List	ICF PS parts list.pdf
ICF PS Chassis Front Panel	PS Front Panel.pdf
ICF PS Chassis Rear Panel	PS Rear Panel.pdf

P-Cad Files (printed circuit board artwork)

Printed Circuit Board Art Work. Requires P-Cad Software to view.

ICF Analog PCB (8 P-Cad documents) ICF Control PCB (3 P-Cad documents)

	MI/RR Ion Clea	ring Field HV Powe	r Supply		
		e, and Camac Control Card			
Par. P.					
Name I:	MADC	Function	V. Level	Cable ID	Burndy Pin
CF60UV	1	ICF Volts PS1 (A)	0 to +10, 50V/V		RG-58
CF60C1	2	ICF nAmps US BPMs A	0 to +10, 100nA/V		RG-58
CF60C2	3	ICF nAmps US BPMs B	0 to +10, 100nA/V		RG-58
CF60DV	3	ICF Volts PS2 (B)	0 to +10, 50V/V		RG-58
CF60C3	4	ICF nAmps DS BPMs A	0 to +10, 100nA/V		RG-58
CF60C4	5	ICF nAmps DS BPMs B	0 to +10, 100nA/V		RG-58
	Camac CC218, 12 bit	, Unipolar Control, 5V Statu	us Interface		
	CC218	PS Function	V. Level	Viking Con.	Wire ID
CF60PS	Control D/A	D/A Output	0 to +10 V	10R	RG- 58
		D/A Return		2L	RG-58 Gnd
	Status Bits	Inputs	C. Sink, Active L		
	0	US PS On	L=On	14R	A BK
	1	US PS Pol	L=Pos	13L	B BRN
	2	US PS OC Trip (NA)	L=No OC	13R	C RED
	3	US PS L/R	L=On	12L	D ORG
	4	DS PS ON	L=Pos	12R	E YEL
	5	DS PS Pol	L=Remote	10L	F GRN
	6	DS PS OC Trip	L= No OC	11R	G BLU
	_	DS L/R	L=Remote	11L	H VIO
	8	Safety S. OK (NA)	L=Safety OK	15L	J GRAY
		Spare			K WH
		Gnd		1R, 1L	L W/BK
				,	
	Control Relays				
	K2 NO	On	On=On/Reset	9R	M W/BRN
	K3 NO	Off	On=Off	5R	N W/RED
	K3 NC	Spare		7R	P W/ORG
	K4 NO	Polarity Pos	On=Pos	6L	R W/YEL
	K5 NO	Polarity Neg		3L	S W/GRN
	K5 NC	Spare	On=Neg	4L	T W/BLU
	K1	Spare		9L	U W/VIO
		Common V+		8R, 5L, 8L	V W/GRAY
		des buildies			
repeat sam	ne pattern for each MI ser	vice building.			
251000	CE20vv	CE20vv	CE40var	CEEDING	CECON
CF10xx	CF20xx	CF30xx	CF40xx	CF50xx	CF60xx

Fig. 2 Acnet parameter page names and Camac card connections.

			+		
	MI/RR Ion C	learing Fiel	d HY Power S	upply	Jim Fitzgerald
					page 2of 2
Location	BPM Sys. Loc.	ICF PS Loc.	CC218 Loc.	MADC Loc.	MADC CH
MI 10	MI 10116	MI10115	\$13/slot 22	\$13/slot 23/#19	40-45
MI20	MI 20116	MI20115	\$23/slot 22	\$23/slot 23/#30	40-45
MI30	MI 30116	Mi30115	\$33/slot 22	\$32/slot 23/#49	50-55 *
MI40	MI40116	MI40115	\$43/slot19	\$43/slot 23/#54	40-45
MI50	MI 50116	MI50115	\$53/slot 22	\$53/slot 23/#58	40-45
MI60 (N.)	MI 60211	MI60211	\$73/slot 19	\$73/slot 23/#38	40-45
					+

Fig. 3 Acnet Camac Crate assignments for the power supply controllers and MADC channels.

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CLEARING ELEC
                                          D/A
                                                A/D
                                                     Com-U ◆COPIES◆
                              Y=B:APGAWM,B:CIGWM ,B:VXBIAS,B BIAS
-<FTP>+ *SA◆ X-A/D
                  X=TIME
                                        , 0
                                                 , 0
                                                          , 0
COMMAND ---- Eng-U I= .058
                              I = 0
                                                 , 10
                   F= .078
                                        , 10
-<24>+ r_12 AUTO
                                                           , 10
                              F= 10
torroid flux... rad_mon dcct... BPM_NOD ipm.... peanuts testdev
-R:CF10PS
             Ion Clearing Field HV PS
                                        500
                                                   500
                                                          VLTS
R:CF10UV
             ICF Volts US BPMs
                                                 * 496.1
                                                          VLTS
R:CF10C1
            ICF nAmps US BPMs A
                                                 * 7.469
                                                          nAmp
            ICF nAmps US BPMS B
R:CF10C2
                                                 * 3.719
                                                          nAmp
R:CF10DV
             ICF Volts DS BPMs
                                                 *-498.8
                                                          VLTS
R:CF10C3
             ICF nAMPs DS BPMs A
                                                 *-4.781
                                                          nAmp
R:CF10C4
            ICF nAmps DS BPMs B
                                                 *-9.781
                                                          nAmp
-R:CF20PS
             Ion Clearing Field HV PS 500
                                                 500
                                                          VLTS
R:CF20UV
             ICF Volts US BPMs
                                                 * 486.6
                                                          VLTS
                                                 * 2.594
R:CF20C1
             ICF nAmps US BPMs A
                                                          nAmp
 R:CF20C2
             ICF nAmps US BPMS B
                                                 * 2.719
                                                          nAmp
R:CF20DV
             ICF Volts DS BPMs
                                                 *-486.8
                                                          VLTS
R:CF20C3
             ICF nAMPs DS BPMs A
                                                 *-2.781
                                                          nAmp
R:CF20C4
             ICF nAmps DS BPMs B
                                                 *-9.156
                                                          nAmp
-R:CF30PS
             Ion Clearing Field HV PS
                                                 500
                                                          VLTS
 R:CF30UV
             ICF Volts US BPMs
                                                 * 493.3
                                                          VLTS
R:CF30C1
             ICF nAmps US BPMs A
                                                 * 1.5
                                                          nAmp
R:CF30C2
             ICF nAmps US BPMS B
                                                 * 8
                                                          nAmp
R:CF30DV
             ICF Volts DS BPMs
                                                 *-507
                                                          VLTS
             ICF nAMPs DS BPMs A
R:CF30C3
                                                 *-6
                                                          nAmp
 R:CF30C4
             ICF nAmps DS BPMs B
                                                          nAmp
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Fig. 4 Acnet Parameter Page, for ICF power supplies at MI10, MI20 and MI30.

Recycl	er Ring	BPM Lo	cations							
MI-10	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP628	VP628	HP632	VP632	HP636	VP636	HP640	VP640	HP102	VP102
chan 2	HP629	VP629	HP633	VP633	HP637	VP637	HP641	VP641	HP103	VP103
chan 3	HP630	VP630	HP634	VP634	HP638	VP638	HP100	VP100	HP104	VP104
chan 4	HP631	VP631	HP635	VP635	HP639	VP639	HP101	VP101	HP105	VP105
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP106	VP106	HP110	VP110	HP114	VP114	HP118	VP118		
chan 2	HP107	VP107	HP111	VP111	HP115	VP115	HP119	VP119		
chan 3	HP108	VP108	HP112	VP112	HP116	VP116	HP120	VP120		
chan 4	HP109	VP109	HP113	VP113	HP117	VP117	HP121	VP121		
MI-20	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP122	VP122	HP126	VP126	HP130	VP130	HP204	VP204	HP208	VP208
chan 2	HP123	VP123	HP127	VP127	HP201	VP201	HP205	VP205	HP209	VP209
chan 3	HP124	VP124	HP128	VP128	HP202	VP202	HP206	VP206	HP210	VP210
chan 4	HP125	VP125	HP129	VP129	HP203	VP203	HP207	VP207	HP211	VP211
	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP212	VP212	HP216	VP217	HP220	VP221	HP703	VP704	HP708	
chan 2	HP213	VP213	HP217	VP218	HP221	VP701	HP704	VP705		
chan 3	HP214	VP215	HP218	VP219	HP701	VP702	HP705	VP707		
chan 4	HP215	VP216	HP219	VP220	HP702	VP703	HP706			
MI-30	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP222	VP222	HP226	VP226	HP230	VP230			HP307A	
chan 2	HP223	VP223	HP227	VP227	HP231	VP231			HP308A	
chan 3	HP224	VP224	HP228	VP228	HP232	VP232		VP307C		VP309
chan 4	HP225	VP225	HP229	VP229		VP301A				VP310
l	slot 11	slot 12	slot 13	slot 14	slot 15	slot 16	slot 17	slot 18	slot 19	slot 20
chan 1	HP311	VP311	HP315	VP315	HP319	VP319	HP323	VP323	HP804	VP806
chan 2	HP312	VP312	HP316	VP316	HP320	VP320	HP324	VP324	HP805	VP807
chan 3	HP313	VP313	HP317	VP317	HP321	VP321	HP325	VP804	HP807	
chan 4	HP314	VP314	HP318	VP318	HP322	VP322	HP803	VP805		
		-1-40	-1-40	-1-4 4		-1-4-0	-1-4 7		-1-40	-1-4 40
MI-40	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 8	slot 9	slot 10
chan 1	HP326	VP325	HP330	VP329	HP334	VP333	HP338	VP337	HP400	VP341
chan 1 chan 2	HP326 HP327	VP325 VP326	HP330 HP331	VP329 VP330	HP334 HP335	VP333 VP334	HP338 HP339	VP337 VP338	HP400 HP401	VP341 VP400
chan 1 chan 2 chan 3	HP326 HP327 HP328	VP325 VP326 VP327	HP330 HP331 HP332	VP329 VP330 VP331	HP334 HP335 HP336	VP333 VP334 VP335	HP338 HP339 HP340	VP337 VP338 VP339	HP400 HP401 HP402	VP341 VP400 VP401
chan 1 chan 2	HP326 HP327 HP328 HP329	VP325 VP326 VP327 VP328	HP330 HP331 HP332 HP333	VP329 VP330 VP331 VP332	HP334 HP335 HP336 HP337	VP333 VP334 VP335 VP336	HP338 HP339 HP340 HP341	VP337 VP338 VP339 VP340	HP400 HP401 HP402 HP403	VP341 VP400 VP401 VP402
chan 1 chan 2 chan 3 chan 4	HP326 HP327 HP328 HP329 slot 11	VP325 VP326 VP327 VP328 slot 12	HP330 HP331 HP332 HP333 slot 13	VP329 VP330 VP331 VP332 slot 14	HP334 HP335 HP336 HP337 slot 15	VP333 VP334 VP335 VP336 slot 16	HP338 HP339 HP340 HP341 slot 17	VP337 VP338 VP339 VP340 slot 18	HP400 HP401 HP402	VP341 VP400 VP401 VP402 slot 20
chan 1 chan 2 chan 3 chan 4 chan 1	HP326 HP327 HP328 HP329 slot 11 HP404	VP325 VP326 VP327 VP328 slot 12 VP403	HP330 HP331 HP332 HP333 slot 13 HP408	VP329 VP330 VP331 VP332 slot 14 VP407	HP334 HP335 HP336 HP337 slot 15 HP412	VP333 VP334 VP335 VP336 slot 16 VP411	HP338 HP339 HP340 HP341 slot 17 HP003	VP337 VP338 VP339 VP340 slot 18 VP002	HP400 HP401 HP402 HP403	VP341 VP400 VP401 VP402 slot 20 VP802
chan 1 chan 2 chan 3 chan 4 chan 1 chan 2	HP326 HP327 HP328 HP329 slot 11 HP404 HP405	VP325 VP326 VP327 VP328 slot 12 VP403 VP404	HP330 HP331 HP332 HP333 slot 13 HP408 HP409	VP329 VP330 VP331 VP332 slot 14 VP407 VP408	HP334 HP335 HP336 HP337 slot 15 HP412 HP413	VP333 VP334 VP335 VP336 slot 16 VP411 VP412	HP338 HP339 HP340 HP341 slot 17 HP003 HP004	VP337 VP338 VP339 VP340 slot 18 VP002 VP003	HP400 HP401 HP402 HP403	VP341 VP400 VP401 VP402 slot 20
chan 1 chan 2 chan 3 chan 4 chan 1	HP326 HP327 HP328 HP329 slot 11 HP404	VP325 VP326 VP327 VP328 slot 12 VP403	HP330 HP331 HP332 HP333 slot 13 HP408	VP329 VP330 VP331 VP332 slot 14 VP407	HP334 HP335 HP336 HP337 slot 15 HP412	VP333 VP334 VP335 VP336 slot 16 VP411	HP338 HP339 HP340 HP341 slot 17 HP003	VP337 VP338 VP339 VP340 slot 18 VP002	HP400 HP401 HP402 HP403	VP341 VP400 VP401 VP402 slot 20 VP802
chan 1 chan 2 chan 3 chan 4 chan 1 chan 2 chan 3	HP326 HP327 HP328 HP329 slot 11 HP404 HP405 HP406	VP325 VP326 VP327 VP328 slot 12 VP403 VP404 VP405	HP330 HP331 HP332 HP333 slot 13 HP408 HP409 HP410	VP329 VP330 VP331 VP332 slot 14 VP407 VP408 VP409	HP334 HP335 HP336 HP337 slot 15 HP412 HP413 HP001	VP333 VP334 VP335 VP336 slot 16 VP411 VP412 VP413	HP338 HP339 HP340 HP341 slot 17 HP003 HP004 HP801	VP337 VP338 VP339 VP340 slot 18 VP002 VP003 VP004	HP400 HP401 HP402 HP403	VP341 VP400 VP401 VP402 slot 20 VP802
chan 1 chan 2 chan 3 chan 4 chan 1 chan 2 chan 3 chan 4	HP326 HP327 HP328 HP329 Slot 11 HP404 HP405 HP406 HP407	VP325 VP326 VP327 VP328 slot 12 VP403 VP404 VP405 VP406	HP330 HP331 HP332 HP333 Slot 13 HP408 HP409 HP410 HP411	VP329 VP330 VP331 VP332 slot 14 VP407 VP408 VP409 VP410	HP334 HP335 HP336 HP337 slot 15 HP412 HP413 HP001 HP002	VP333 VP334 VP335 VP336 slot 16 VP411 VP412 VP413 VP001	HP338 HP339 HP340 HP341 slot 17 HP003 HP004 HP801 HP802	VP337 VP338 VP339 VP340 slot 18 VP002 VP003 VP004 VP801	HP400 HP401 HP402 HP403 slot 19	VP341 VP400 VP401 VP402 slot 20 VP802 VP803
chan 1 chan 2 chan 3 chan 4 chan 1 chan 2 chan 3 chan 4 MI-50	HP326 HP327 HP328 HP329 slot 11 HP404 HP405 HP406 HP407 slot 1	VP325 VP326 VP327 VP328 slot 12 VP403 VP404 VP405 VP406 slot 2	HP330 HP331 HP332 HP333 slot 13 HP408 HP409 HP410 HP411 slot 3	VP329 VP330 VP331 VP332 slot 14 VP407 VP408 VP409 VP410 slot 4	HP334 HP335 HP336 HP337 slot 15 HP412 HP413 HP001 HP002 slot 5	VP333 VP334 VP335 VP336 slot 16 VP411 VP412 VP413 VP001 slot 6	HP338 HP339 HP340 HP341 slot 17 HP003 HP004 HP801 HP802 slot 7	VP337 VP338 VP339 VP340 slot 18 VP002 VP003 VP004 VP801 slot 8	HP400 HP401 HP402 HP403 slot 19	VP341 VP400 VP401 VP402 slot 20 VP802 VP803
chan 1 chan 2 chan 3 chan 4 chan 1 chan 2 chan 3 chan 4 MI-50 chan 1	HP326 HP327 HP328 HP329 slot 11 HP404 HP405 HP406 HP407 slot 1 HP414	VP325 VP326 VP327 VP328 slot 12 VP403 VP404 VP405 VP406 slot 2 VP414	HP330 HP331 HP332 HP333 slot 13 HP408 HP409 HP410 HP411 slot 3 HP418	VP329 VP330 VP331 VP332 slot 14 VP407 VP408 VP409 VP410 slot 4 VP418	HP334 HP335 HP336 HP337 slot 15 HP412 HP413 HP001 HP002 slot 5 HP422	VP333 VP334 VP335 VP336 slot 16 VP411 VP412 VP413 VP001 slot 6 VP422	HP338 HP339 HP340 HP341 slot 17 HP003 HP004 HP801 HP802 slot 7 HP426	VP337 VP338 VP339 VP340 slot 18 VP002 VP003 VP004 VP801 slot 8 VP426	HP400 HP401 HP402 HP403 slot 19 slot 9 HP430	VP341 VP400 VP401 VP402 slot 20 VP802 VP803 slot 10 VP430
chan 1 chan 2 chan 3 chan 4 chan 1 chan 2 chan 3 chan 4 MI-50 chan 1 chan 2	HP326 HP327 HP328 HP329 slot 11 HP404 HP405 HP406 HP407 slot 1 HP414 HP415	VP325 VP326 VP327 VP328 slot 12 VP403 VP404 VP405 VP406 slot 2 VP414 VP415	HP330 HP331 HP332 HP333 slot 13 HP408 HP409 HP410 HP411 slot 3 HP418 HP419	VP329 VP330 VP331 VP332 slot 14 VP407 VP408 VP409 VP419 Slot 4 VP418 VP419 VP420 VP420 VP421	HP334 HP335 HP336 HP337 slot 15 HP412 HP413 HP001 HP002 slot 5 HP422 HP423	VP333 VP334 VP335 VP336 slot 16 VP411 VP412 VP413 VP001 slot 6 VP422 VP423	HP338 HP339 HP340 HP341 slot 17 HP003 HP004 HP801 HP802 slot 7 HP426 HP427	VP337 VP338 VP339 VP340 slot 18 VP002 VP003 VP004 VP801 slot 8 VP426 VP427	HP400 HP401 HP402 HP403 slot 19 Slot 9 HP430 HP501	VP341 VP400 VP401 VP402 slot 20 VP802 VP803 slot 10 VP430 VP501
chan 1 chan 2 chan 3 chan 4 chan 1 chan 2 chan 3 chan 4 MI-50 chan 1 chan 2 chan 3	HP326 HP327 HP328 HP329 slot 11 HP404 HP405 HP406 HP407 slot 1 HP414 HP415 HPR16	VP325 VP326 VP327 VP328 slot 12 VP403 VP404 VP405 VP406 slot 2 VP414 VP415 VP416	HP330 HP331 HP332 HP333 slot 13 HP408 HP409 HP410 HP411 slot 3 HP418 HP419 HP420	VP329 VP330 VP331 VP332 slot 14 VP407 VP408 VP409 VP410 slot 4 VP418 VP419 VP420	HP334 HP335 HP336 HP337 slot 15 HP412 HP413 HP001 HP002 slot 5 HP422 HP423 HP424	VP333 VP334 VP335 VP336 slot 16 VP411 VP412 VP413 VP001 slot 6 VP422 VP423 VP424	HP338 HP339 HP340 HP341 slot 17 HP003 HP004 HP801 HP802 slot 7 HP426 HP427 HP428	VP337 VP338 VP339 VP340 slot 18 VP002 VP003 VP004 VP801 slot 8 VP426 VP427 VP428	HP400 HP401 HP402 HP403 slot 19 Slot 9 HP430 HP501 HP502	VP341 VP400 VP401 VP402 slot 20 VP802 VP803 Slot 10 VP430 VP501 VP502
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Fig. 5 A List of the Recycler BPMs connected to the Ion Clearing Field HV power supplies.

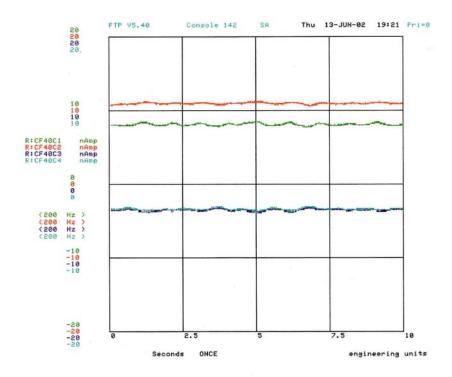


Fig. 6 Fast time plot of current measurement showing the offset and noise pickup for ICF power supply at MI40. The PS voltage was set at 300V.

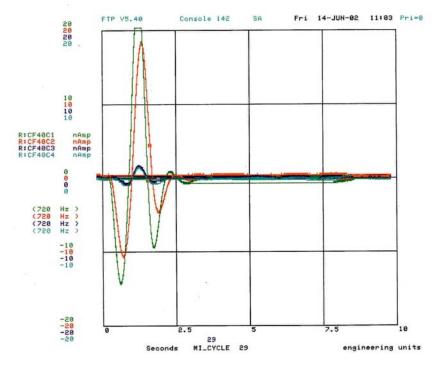


Fig. 7 Fast time plot of current measurement showing interference from MI ramp.

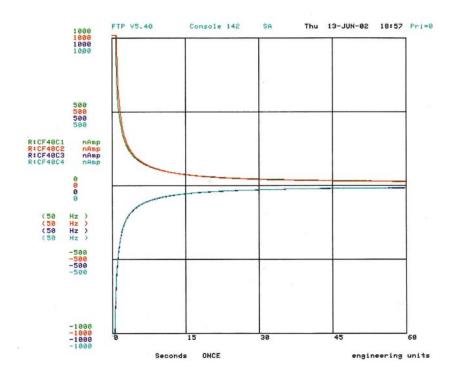


Fig. 8 Fast time plot showing current levels and time required for charging cable to 300 Volts.